



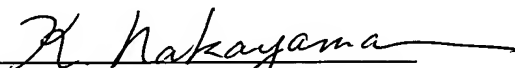
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## DECLARATION

I, Koki Nakayama of SHIGA INTERNATIONAL PATENT OFFICE, 2-3-1, Yaesu, Chuo-ku, Tokyo, Japan, understand both English and Japanese, am the translator of the English document attached, and do hereby declare and state that the attached English document contains an accurate translation of the US patent specification filed on September 29, 2003, under the filing number 10/671,445, and that all statements made herein are true to the best of my knowledge.

Declared in Tokyo, Japan

This 18<sup>TH</sup> of June, 2004

  
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14789JS

HYDROGEN STORAGE ALLOY, HYDROGEN STORAGE ALLOY UNIT AND  
HEAT PUMP AND HYDROGEN COMPRESSION APPARATUS THAT UTILIZE  
THE HYDROGEN STORAGE ALLOY

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BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a hydrogen storage alloy, hydrogen storage alloy unit, and a heat pump and hydrogen compression apparatus that utilize the hydrogen storage alloy.

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Description of Related Art

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Conventionally, when a plurality of hydrogen storage alloys are used, because a heating medium source and a hydrogen extraction path have to be provided for each hydrogen storage alloy, the apparatus has been complex and of considerable size. In addition, it has been necessary to prepare a large amount of heating medium source. There is also a great deal of heat loss when a hydrogen storage alloy is switched between heating and cooling. Furthermore, if the hydrogen storage alloy is fixed in position, then there have been cases in which the container housing the hydrogen metal alloy has been shattered due to the expansion that occurs during hydrogenation of the hydrogen storage alloy.

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In contrast, in a heat pump that uses a conventional hydrogen storage alloy, it is difficult to attain ultra low temperatures, and to attain such temperatures it has been necessary to employ a large scale apparatus.

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Moreover, in a conventional hydrogen compression apparatus, because it has hitherto been easy for hydrogen to leak from the gap between a piston ring and the

internal wall of a cylinder in a compressor, achieving high levels of compression has been difficult.

Furthermore, when a hydrogen storage alloy in a powder form is used, if the container housing the hydrogen storage alloy is vibrated, the vibration causes the hydrogen storage alloy inside the container to congregate on one side thereof.

Consequently, there have been cases in which the container housing the hydrogen metal alloy has been shattered due to the expansion that occurs during hydrogenation of the hydrogen storage alloy.

Examples of related technology include Japanese Unexamined Patent Application, First Publication Nos. H02-110263, S60-9839, 2000-45926, H04-232202, H02-188401, and S63-161368; Japanese Utility Model (Registered) Publication No. 2528621; and United States Patent No. 4,609,038.

The present invention was conceived in view of the above circumstances and it is a first object of the present invention to provide a hydrogen absorbing alloy unit that has a compact apparatus, that has only a small amount of heat loss when switching between heating and cooling of a hydrogen absorbing alloy while at the same time hastening heat propagation, and that has little chance of the container housing the hydrogen metal alloy being shattered due to the hydrogenation expansion of the hydrogen absorbing alloy.

The second object of the present invention is to provide a heat pump that allows ultra low temperatures to be attained while having a compact structure.

The third object of the present invention is to provide a hydrogen compression apparatus that enables hydrogen to be compressed at higher pressure.

The fourth object of the present invention is to provide a hydrogen absorption alloy apparatus in which a hydrogen absorption alloy that is housed in a container is not

made to accumulate on one side of the container as a result of the container being vibrated.

### SUMMARY OF THE INVENTION

5           In order to solve the above problems, the first aspect of the present invention is a hydrogen storage alloy in which a eutectic mixture in powder form of a hydrogen storage alloy material with a hydrogen absorbing material is mixed with a viscous substance to form a paste.

          The second aspect of the present invention is a hydrogen storage alloy unit  
10   having a heat exchange chamber through which a heating medium source circulates, a pair of hydrogen chambers formed on both sides of the heat exchange chamber, and hydrogen storage alloy pipe groups, one end portion of which imports into the pair of hydrogen chambers, and whose other end portion extends in a free state into the heat exchange chamber, and that form a pair whose one end portions that are on the side of the  
15   pair of hydrogen chambers are each fixed on that side, wherein the hydrogen storage alloy pipe groups comprise hydrogen storage alloy pipes provided a hydrogen storage alloy inside, the free end portion on the heat exchange chamber side of the hydrogen storage alloy pipe is closed off, and hydrogen circulation holes are opened in the end portions on the hydrogen chamber sides of the hydrogen storage alloy pipe.

20           It is preferable that the hydrogen storage alloy pipes that form a pair are arranged in a honeycomb pattern. By making the dissociation pressures of the hydrogen storage alloys inside the hydrogen storage alloy pipes that form a pair different, it is possible to perform the simultaneous absorption and discharge of hydrogen using a common heating medium source.

25           It is structurally preferable if the hydrogen storage alloy pipes that form a pair

each having a pound material formed by a porous material that has the hydrogen circulation holes in a central portion thereof, and a hydrogen storage alloy paste hardened after being inserted in a paste form between the pound material and an outer pipe.

It is also preferable if carbon fiber or carbide fiber is wrapped around an outer  
5 circumference of the hydrogen storage alloy pipes.

The third aspect of the present invention is a heat pump having a first hydrogen storage alloy apparatus provided with a first hydrogen storage alloy having a predetermined dissociation pressure, a second hydrogen storage alloy apparatus provided with a second hydrogen storage alloy having a dissociation pressure that is higher than  
10 that of the first hydrogen storage alloy, a third hydrogen storage alloy apparatus provided with a third hydrogen storage alloy having a dissociation pressure that is higher than that of the second hydrogen storage alloy, and a fourth hydrogen storage alloy apparatus provided with a fourth hydrogen storage alloy having a dissociation pressure that is  
15 higher than that of the third hydrogen storage alloy, wherein the second hydrogen storage alloy apparatus and the third hydrogen storage alloy apparatus form a single unit, and the unit having a first hydrogen storage alloy pipe group that has the second hydrogen storage alloy, a first hydrogen chamber in which one end of the first hydrogen storage alloy pipes are fixed, a second hydrogen storage alloy pipe group that has the third  
20 hydrogen storage alloy, and a second hydrogen chamber in which one end of the second hydrogen storage alloy pipes are fixed, wherein another end of the second hydrogen storage alloy pipes and another end of the third hydrogen storage alloy pipes are placed inside a common heat exchange chamber, the first hydrogen storage alloy apparatus is connected to one of the second hydrogen storage alloy apparatus and the third hydrogen storage alloy apparatus, the fourth hydrogen storage alloy apparatus is connected to the  
25 other of the second hydrogen storage alloy apparatus and the third hydrogen storage alloy

apparatus, and the first hydrogen storage alloy apparatus and the fourth hydrogen storage alloy apparatus each cause hydrogen to be transported to the unit as a result of one of the first through fourth hydrogen absorption apparatuses being heated or cooled.

In the above described heat pump, it is preferable if the second hydrogen storage alloy apparatus and the fourth hydrogen storage alloy apparatus are connected via a pump that is able to transport hydrogen from the fourth hydrogen storage alloy apparatus to the second hydrogen storage alloy apparatus.

It is also preferable if carbon fiber or carbide fiber is wrapped around an outer circumference of the hydrogen storage alloy pipes used in the above described heat pump.

The fourth aspect of the present invention is a heat pump having a first hydrogen storage alloy apparatus provided with a first hydrogen storage alloy having a predetermined dissociation pressure, a second hydrogen storage alloy apparatus provided with a second hydrogen storage alloy having a dissociation pressure that is lower than that of the first hydrogen storage alloy, a third hydrogen storage alloy apparatus provided with a third hydrogen storage alloy having a dissociation pressure that is lower than that of the first hydrogen storage alloy, and a fourth hydrogen storage alloy apparatus provided with a fourth hydrogen storage alloy having a dissociation pressure that is lower than that of the first hydrogen storage alloy, wherein the first hydrogen storage alloy apparatus and the second hydrogen storage alloy apparatus form a first system connected by a pump unit, the third hydrogen storage alloy apparatus and the fourth hydrogen storage alloy apparatus form a second system connected by the pump unit, in the first and second systems, by heating or cooling one hydrogen storage alloy apparatus and also operating the pump unit, hydrogen is transported in mutually opposite directions between the first hydrogen storage alloy apparatus and the second hydrogen storage alloy

apparatus and between the third hydrogen storage alloy apparatus and the fourth hydrogen storage alloy apparatus.

The fifth aspect of the present invention is a hydrogen compression apparatus having a hydrogen storage alloy apparatus provided with a hydrogen storage alloy  
5 formed by mixing a viscous substance with a eutectic mixture in powder form of a hydrogen storage alloy material and a hydrogen absorbing material, and that is capable of transferring heat between itself and a heating medium source, and a hydrogen storage container connected to the hydrogen storage alloy apparatus via a pump, wherein, by heating the hydrogen storage alloy apparatus using the heating medium source and by  
10 also operating the pump such that hydrogen is transported from the hydrogen storage alloy apparatus to the hydrogen storage container, hydrogen can be stored under pressure in the hydrogen storage container.

The sixth aspect of the present invention is a hydrogen compression apparatus having a hydrogen storage alloy apparatus having a hydrogen storage alloy, a first  
15 pressure container and a second pressure container each switchably connected to the hydrogen storage alloy apparatus, a pump that is capable of transporting a fluid and connected to both the first pressure container and the second pressure container, and a hydrogen storage container connected to both the first pressure container and the second pressure container, wherein hydrogen is stored under pressure in the hydrogen storage  
20 container by operating the pump such that hydrogen discharged from the hydrogen storage alloy when the hydrogen storage alloy apparatus is heated is transported to one of the first pressure container and the second pressure container, and fluid is transported from the one of the first pressure container and the second pressure container to which the hydrogen was transported to the other side.

## BRIEF DESCRIPTION THE DRAWINGS

Fig. 1 is a vertical cross-sectional view showing the structure of a hydrogen storage alloy unit according to a first embodiment of the present invention.

Fig. 2A is a cross-sectional view taken in the direction IIA to IIA in Fig. 1.

5 Fig. 2B is a cross-sectional view taken in the direction IIB to IIB in Fig. 1.

Fig. 3A is an axial orthogonal cross-sectional view showing the structure of a hydrogen storage alloy pipe according to the first embodiment of the present invention.

Fig. 3B is a perspective view showing the structure of a hydrogen storage alloy pipe according to the first embodiment of the present invention.

10 Fig. 4A is a schematic structural view of a heat pump according to a second embodiment of the present invention, and shows an ultra low temperature formation step.

Fig. 4B is a schematic structural view of a heat pump according to the second embodiment of the present invention, and shows a reactivation step.

15 Fig. 5 is a schematic structural view of a heat pump according to the third embodiment of the present invention.

Fig. 6A is a schematic structural view showing a hydrogen compression apparatus according to a fourth embodiment of the present invention, and shows a hydrogen storage step.

20 Fig. 6B is a schematic structural view showing a hydrogen compression apparatus according to a fourth embodiment of the present invention, and shows a hydrogen compression step.

Fig. 7 is a schematic structural view of a hydrogen compression apparatus according to a fifth embodiment of the present invention.



Embodiments of the hydrogen storage alloy and hydrogen storage alloy unit according to the present invention, as well as of a hydrogen compression apparatus and a heat pump that utilizes the hydrogen storage alloy will now be described in detail with reference made to the drawings.

5 (First embodiment: Hydrogen storage alloy unit)

The overall structure of a hydrogen storage alloy unit 10 according to the first embodiment will now be described with reference to Figs. 1 to 3.

The hydrogen storage alloy unit 10 has a substantially cylindrically shaped main body portion 11, outwardly protruding end plate portions 12 and 13 that seal off both end portions of the main body portion 11, and bowl shaped portions 22 and 23 that are welded onto the outer side of the end plate portions 12 and 13, and that form sealed hydrogen chambers 32 and 33 respectively between the bowl shaped portions 22 and 23 and the end plate portions 12 and 13. The end plate portions 12 and 13 and the bowl shaped portions 22 and 23 that serve as side walls forming the hydrogen chambers 32 and 33 are sufficiently thick to withstand high pressure. The hydrogen storage alloy unit 10 can be formed from a metal material such as, for example, titanium, stainless steel, aluminum and the like.

Nozzles 14 and 15 are provided respectively at the end plate portion 12 side and the end plate portion 13 side in the main body portion 11 of the hydrogen storage alloy unit 10. The nozzles 14 and 15 are both connected to heating medium sources (not shown) positioned at an outer side of the hydrogen storage alloy unit 10, and are also connected to a heat exchange chamber 16 in the interior of the hollow main body portion 11. Accordingly, by adjusting or selecting the temperature of the heating medium source connected to the nozzle 14 or 15, it is possible to adjust the atmospheric temperature of the heat exchange chamber 16. As the heating medium source, the

natural outside temperature including snow and ice, solar heat, geothermal heat, factory waste heat, heat from garbage burning, combustion heat such as from burning fuel, fuel cell waste heat, and waste heat from operating machinery and the like can be used.

A nozzle (i.e., a hydrogen nozzle) 24 and a nozzle (i.e., a hydrogen nozzle) 25  
5 that connect the hydrogen chambers 32 and 33 with the outside are provided in the bowl shaped portions 22 and 23 that form the hydrogen chambers 32 and 33.

A first and second (group) of hydrogen storage alloy pipes 41 and 42 each having the same structure are arranged in a honeycomb pattern in the heat exchange chamber 16. One closed end 41a (i.e., free end) of the first hydrogen storage alloy pipes  
10 41 is inside the heat exchange chamber 16, while the other, open end 41b thereof (i.e., a fixed end) opens into the interior of the hydrogen chamber 32 by penetrating the end plate portion 12 via an airtight seal. In the same way, one closed end 42a of the hydrogen storage alloy pipes 42 is inside the heat exchange chamber 16, while the other, open end 42b thereof opens into the interior of the hydrogen chamber 33 by penetrating  
15 the end plate portion 13 via an airtight seal. End portions only of the first and second hydrogen storage alloy pipes 41 and 42 that are on the hydrogen chamber 32 and 33 sides are fixed respectively to the end plate portions 12 and 13. Therefore, even if the hydrogen storage alloy pipes 41 and 42 are expanded by heat, because the free ends 41a and 42a are able to extend, breakages of the pipes can be avoided. In addition, if a  
20 structure such as this is employed, because the pipes can be provided extremely close to each other, the quantity of heating medium source that is supplied to the interior of the heat exchange chamber 16 can be reduced, thereby enabling the heat loss when switching heating medium sources when heating or cooling the hydrogen storage alloy pipes 41 and 42 to be reduced to a minimum. Note that the hydrogen storage alloy pipes 41 and 42  
25 can be formed, for example, from titanium or stainless steel.

It is preferable that carbon fiber or carbide fiber (for example, SiC) is wrapped around the outer circumference of the hydrogen storage alloy pipes 41 and 42. By employing such a structure it is possible to achieve a hydrogen storage alloy unit 10 that is lightweight and yet is extremely resistant to pressure.

5           When the temperature inside the heat exchange chamber 16 is raised by the heating medium source to which the nozzle 14 or 15 is connected, and reaches the vicinity of the hydrogen absorption temperature, hydrogen is discharged from the hydrogen storage alloy positioned inside the hydrogen storage alloy pipes 41 and 42. The discharged hydrogen moves from the open, fixed end 41b or 42b into the hydrogen  
10   chamber 32 or 33, and is discharged to the outside of the hydrogen storage alloy unit 10. In contrast, if the temperature inside the heat exchange chamber 16 that had been higher than the hydrogen discharge temperature is lowered by the heating medium source connected to the nozzle 14 or 15, or by being left at room temperature so that it reaches the hydrogen discharge temperature, hydrogen is absorbed by the hydrogen storage alloy  
15   placed inside the hydrogen storage alloy pipe 41 or 42.

          In the hydrogen storage alloy pipes 41 and 42, production heat generated by the heat discharge or heat absorption when the hydrogen storage alloy of one hydrogen storage alloy pipe absorbs (i.e., hydrogenates) or discharges hydrogen can be received by the hydrogen storage alloy of the other hydrogen storage alloy pipe which then  
20   discharges or absorbs (i.e., hydrogenates) hydrogen.

          In addition, because the hydrogen storage alloy pipes 41 and 42 are positioned so as to be in contact with each other, only a small quantity of heating medium needs to be used. Therefore, the switching of the temperature inside the heat exchange chamber 16 when the heating medium is altered can be performed quickly.

25           Furthermore, if the dissociation pressures of the hydrogen storage alloys used in

the hydrogen storage alloy pipes 41 and 42 are made different from each other, and the hydrogen storage alloy pipes 41 and 42 are heated or cooled to the same temperature by a common heating medium source, then the effect can be achieved that one hydrogen storage alloy pipe discharges hydrogen while the other hydrogen storage alloy pipe  
5 absorbs hydrogen.

The (group of) hydrogen storage alloy pipes 41 and 42 have the above described functions. Next, preferred embodiments of the hydrogen storage alloy pipes 41 and 42 will be described with reference to Fig. 3. Because the structures of the hydrogen storage alloy pipes 41 and 42 are the same, only the hydrogen storage alloy pipe 41 is  
10 described here. It is to be understood that it is also possible for the hydrogen storage alloy pipes 41 and 42 to have different structures.

The hydrogen storage alloy pipe 41 forms a uniform cross section having a metal, cylindrical member 41f, hydrogen storage alloy paste 41g, pound material 41c, and a metal plate 41d. The free end 41a of the cylindrical member 41f is closed. The  
15 length of the metal plate 41d extends in the radial direction of the cylindrical member 41f, and waveform curved portions 41d' are formed in a center portion thereof. The pound material 41c is a porous member (i.e., a material that allows hydrogen to pass through it) that forms substantially semicircular columns positioned at a front and rear of the metal plate 41d. Hydrogen circulation holes 41e are formed between the waveform curved  
20 portions 41d' of the metal plate 41 and the pound material 41c. These hydrogen circulation holes 41e open onto the hydrogen chamber 32. A material that has excellent heat resistance as well as being able to extend and retract is preferably used as the pound material 41c and, for example, a foam silicon rubber agent may be used.

The gap between the pound material 41c and the cylindrical member 41f is filled  
25 with the hydrogen storage alloy paste 41g, which is then hardened. By using a paste

form of hydrogen storage alloy material, it is possible to prevent scattering of powdered hydrogen storage alloy material, and because rapid heat propagation can be achieved, it is also possible to shorten the reaction time needed for the hydrogenation within the hydrogen storage alloy material and for the discharge of hydrogen to the outside. In addition, there is no displacement of the hydrogen storage alloy contained inside the cylindrical member 41 as a result of vibration.

Note that it is also possible to not use the pound material 41c and the metal plate 41d, but instead to form a film of the hydrogen storage alloy paste 41g on the internal wall of the cylindrical member 41f and to use the interior of the hydrogen storage alloy paste 41g as hydrogen circulation holes. It is also possible to form the hydrogen storage alloy paste 41g by first coating an adhesive on the internal wall and then adhering a hydrogen storage alloy material onto the cylindrical member 41f.

Here, it is preferable that a mixture of a polymer based adhesive with a hydrogen storage alloy substance in powder form whose particle diameter has previously been adjusted to between approximately 20 and 50  $\mu\text{m}$  is used as the hydrogen storage alloy paste 41g. However, it is also possible to use a paste formed by mixing a eutectic mixture (i.e., a eutectic body) of a hydrogen storage alloy material and a hydrogen absorbing material in powder form with a viscous substance such as an adhesive. By using a eutectic mixture, it is possible to increase the ratio of the hydrogen absorption weight relative to the alloy weight. In addition, because a hydrogen absorbing material has the property of increasing its hydrogen absorption quantity as the pressure is increased, it is able to take on a greater quantity of hydrogen than when a hydrogen storage alloy material is used by itself. This effect is conspicuous in a hydrogen storage alloy unit that allows a high pressure to be achieved such as in the present invention.

Examples of a material that can be used as the hydrogen storage alloy material

include Ca, La, Mg, Ni, and Ti, LaNi based alloys, MgTi based alloys, and eutectic mixtures that into which a V based original element has been introduced using a mechanical alloying method.

In contrast, examples of a material that can be used as the hydrogen absorbing  
5 include carbon materials, nanocarbons having a graphite structure or an amorphous structure, carbides, and oxides. However, if nanocarbons are used as the hydrogen absorbing material, then nanocarbons are blended into the hydrogen storage alloy material during the manufacturing of the eutectic mixture so that the hydrogen storage alloy material is carbonized. Therefore, it is preferable to first form a coating film of  
10 hydrogen dissociative metal, carbide or oxide on nanocarbon fine particles. The formation of this coating film is performed by selecting a method to correspond to the type and the like of the nanocarbons from among film formation methods such as wet plating, CVD, and PVD.

In eutectic mixtures of these types of film-coated nanocarbons, carbides and  
15 oxides with a hydrogen storage alloy material, due to the hydrogen dissociative properties of the hydrogen storage alloy material around the carbons, carbides, and oxides, hydrogen molecules ( $H_2$ ) in the gas are separated into protons (H) when they come into contact with the hydrogen storage alloy material which then adhere to the surfaces of the fine particles of the hydrogen absorbing material and also to the gaps  
20 between these fine particles, thereby enabling a greater quantity of hydrogen to be absorbed.

Furthermore, it is also possible to use a rubber agent instead of the above described adhesive. Namely, as the hydrogen storage alloy paste 41g, it is possible to use a paste obtained by mixing, for example, a silicon rubber agent together with a  
25 powder of a hydrogen storage alloy material by itself or with a powder of a eutectic

mixture of a hydrogen storage alloy material and a hydrogen absorbing material. In this case, the hydrogen storage alloy paste 41g with which the cylindrical member 41f is filled can be hardened by heating the hydrogen storage alloy pipe 41.

In the hydrogen storage alloy unit 10 having the above described structure, by  
5 setting the temperature of the heating medium source connected to the nozzle 14 or the nozzle 15 to a predetermined temperature, it is possible to adjust the temperature of the heat exchange chamber 16. Hydrogen discharge is begun when the temperature of the heating medium source is raised so that the temperature of the heat exchange chamber 16 reaches the hydrogen discharge temperature of one of or both of the hydrogen storage  
10 alloy pipes 41 and 42. Hydrogen that is discharged from the hydrogen storage alloy pipe 41 flows from the nozzle 24 to the outside via the hydrogen chamber 32, while hydrogen that is discharged from the hydrogen storage alloy pipe 42 flows from the nozzle 25 to the outside via the hydrogen chamber 33. In contrast, hydrogen absorption is begun when the temperature of the heating medium source is lowered so that the  
15 temperature of the heat exchange chamber 16 reaches the hydrogen absorbing temperature of one of or both of the hydrogen storage alloy pipes 41 and 42. Inside the hydrogen storage alloy pipe 41, hydrogen inside the hydrogen chamber 32 and inside external equipment connected to the nozzle 24 is gradually absorbed by the hydrogen storage alloy of the hydrogen storage alloy pipe 41, while inside the hydrogen storage  
20 alloy pipe 42, hydrogen inside the hydrogen chamber 33 and inside external equipment connected to the nozzle 25 is gradually absorbed by the hydrogen storage alloy of the hydrogen storage alloy pipe 42. Alternatively, by placing the interiors of the heat exchange chambers 32 and 33 and of the pipes 41 and 42 in a vacuum via the nozzles 24 and 25 while raising the temperature of the heating medium source connected to the  
25 nozzle 14 or 15 to approximately 80°C so as to deaerate the hydrogen storage alloy,

because it is then possible to place the heating medium source at a cooling temperature of approximately 5°C and pressurize the hydrogen via the nozzles 24 and 25 to approximately 30 kg/cm<sup>2</sup>, it is possible to activate the hydrogen storage alloy directly immediately after it is completed without using a dedicated chamber.

5           In addition, because the pressure resistance of the hydrogen storage alloy pipes 41 and 42 is improved by wrapping carbon fiber or carbide fiber (for example, SiC) around them, the interior of the hydrogen storage alloy unit 10 can be placed under high pressure. As a result, in the hydrogen storage alloy of the present invention that contains a hydrogen absorbing material that absorbs a greater quantity of hydrogen if the  
10       pressure is higher, a greater quantity of hydrogen can be taken on than when a hydrogen storage alloy material is used by itself.

          Furthermore, the hydrogen storage alloy unit 10 can be used in a hydrogen station or in a hydrogen fueled vehicle as a high-pressure resistant, lightweight hydrogen storage container by not installing the hydrogen storage alloy and hydrogen absorbing  
15       material inside the hydrogen storage alloy pipes 41 and 42. In this case, compared with a conventional gas cylinder type of hydrogen storage container, it is easier using the heating medium source to cool high temperature heat that is generated by the fluid friction that arises when the hydrogen storage container is filled with high pressure hydrogen, and to thereby greatly shorten the high pressure hydrogen filling time.

20       (Second Embodiment: Heat pump)

          A heat pump 50 according to the second embodiment will now be described with reference to Figs. 4A and 4B.

          The heat pump 50 has four hydrogen storage alloy apparatuses each having a different hydrogen dissociation pressure, namely, a hydrogen storage alloy apparatus (i.e.,  
25       first hydrogen storage alloy apparatus) 60, a hydrogen storage alloy apparatus (i.e., a



third hydrogen storage alloy apparatus) 61, a hydrogen storage alloy apparatus (i.e., second hydrogen storage alloy apparatus) 62, and a hydrogen storage alloy apparatus (i.e., a fourth hydrogen storage alloy apparatus) 63. Heating medium sources 70, 71, 72, and 73 are each removably connected to the hydrogen storage alloy apparatuses 60 and 63, while the common heating medium source 71 is connected to the hydrogen storage alloy apparatuses 61 and 62. In addition, a pump 74 that is able to transfer hydrogen generated by the hydrogen storage alloy apparatus 63 to the hydrogen storage alloy apparatus 62 is placed between the hydrogen storage alloy apparatuses 62 and 63 so as to connect the hydrogen storage alloy apparatuses 62 and 63. Note that the heating medium source 71 is able to be selectively connected to one of either the hydrogen storage alloy apparatuses 61 and 62 or the hydrogen storage alloy apparatus 63. As the heating medium sources 70, 71, and 72, the natural outside temperature including snow and ice, solar heat, geothermal heat, factory waste heat, heat from garbage burning, combustion heat such as from burning fuel, fuel cell waste heat, and waste heat from operating machinery and the like can be used.

Although shown in abbreviated form in Figs. 4A and 4B, the hydrogen storage alloy apparatuses 61 and 62 form the hydrogen storage alloy unit 10 shown in Fig. 1. Namely, the hydrogen storage alloy apparatuses 61 and 62 respectively form one of the hydrogen storage alloy pipes 41 and 42 in the hydrogen storage alloy unit 10, and are respectively connected by the nozzle 24 and the nozzle 25 to the hydrogen storage alloy apparatus 60 and the pump 74. The heating medium source 71 is connected to the nozzles 14 and 15. The number of hydrogen storage alloy apparatuses may be optionally set, and the number of hydrogen storage alloy apparatuses forming the hydrogen storage alloy unit 10 shown in Fig. 1 may be two or more. It is preferable that carbon fiber or carbide fiber (for example, SiC) is wrapped around the outer

circumference of the hydrogen storage alloy pipes 41 and 42. By employing such a structure it is possible to achieve a hydrogen storage alloy apparatus for a heat pump that is extremely resistant to pressure.

The hydrogen dissociation pressures of the hydrogen storage alloys of the hydrogen storage alloy apparatuses 60, 61, 62, and 63 are arranged such that that of the hydrogen storage alloy of the hydrogen storage alloy apparatus 60 is the smallest, that of the hydrogen storage alloys of the hydrogen storage alloy apparatuses 62 and 61 increase in that order, and that of the hydrogen storage alloy of the hydrogen storage alloy apparatus 63 is the greatest. Accordingly, the hydrogen discharge start temperature is highest for the hydrogen storage alloy of the hydrogen storage alloy apparatus 60, is lower for the hydrogen storage alloys of the hydrogen storage alloy apparatuses 62 and 61 in that order, and is the lowest for the hydrogen storage alloy of the hydrogen storage alloy apparatus 63.

Examples of the hydrogen storage alloy material that can be used in the hydrogen storage alloy apparatuses 60, 61, 62, and 63 include Ca, La, Mg, Ni, and Ti, as well as LaNi based alloys and MgTi based alloys. In this case, if a mixture of a polymer based adhesive with a single hydrogen storage alloy material in powder form whose particle diameter has previously been adjusted to between approximately 20 and 50  $\mu\text{m}$  is used, then this is desirable at least for a heat pump due to its minimum hysteresis property value.

Due to the hydrogen dissociation properties of this type of hydrogen storage alloy material, gaseous hydrogen molecules ( $\text{H}_2$ ) are separated into protons (H) when they come into contact with the hydrogen storage alloy material, and are accumulated between alloy crystals.

Furthermore, it is also possible to use a rubber agent instead of the above

described adhesive. Namely, as the hydrogen storage alloy paste 41g it is possible to use a paste obtained by mixing, for example, a silicon rubber agent together with a powder of a hydrogen storage alloy material. In this case, the hydrogen storage alloy paste 41g with which the cylindrical member 41f is filled can be hardened by heating the  
5 hydrogen storage alloy pipe 41.

Note that the hydrogen storage alloy apparatuses 60 and 63 can be given optional structures, and it is possible, for example, to employ a structure in which the hydrogen storage alloy is placed inside a pipe such as the hydrogen storage alloy pipe 41 shown in Fig. 3.

10 In the heat pump 50 having the above described structure, it is possible to achieve a single cycle that is formed by an ultra low temperature formation step (Fig. 4A) in which hydrogen is sent respectively from the hydrogen storage alloy apparatus 63 to the hydrogen storage alloy apparatus 62 and from the hydrogen storage alloy apparatus 61 to the hydrogen storage alloy apparatus 60, and heat is captured from the heating  
15 medium source 73; and by a reactivation step in which hydrogen is sent respectively from the hydrogen storage alloy apparatus 60 to the hydrogen storage alloy apparatus 61 and from the hydrogen storage alloy apparatus 62 to the hydrogen storage alloy apparatus 63. In addition, because the pressure resistance of the hydrogen absorption alloy pipes 41 and 42 is improved by wrapping carbon fiber or carbide fiber (for example, SiC)  
20 around them, the interiors of the hydrogen absorption alloy apparatuses 60, 61, 62, and 63 can be placed under high pressure. Consequently, in the hydrogen storage alloy of the present invention that contains a hydrogen absorbing material that absorbs a greater quantity of hydrogen if the pressure is higher, a greater quantity of hydrogen can be taken on than when a hydrogen storage alloy material is used by itself.

25 In the formation step shown in Fig. 4A, if the hydrogen storage alloy apparatus

60 which is at a high temperature is cooled to room temperature by the heating medium source 70, then due to the difference between the hydrogen dissociation pressures of the hydrogen storage alloy of the hydrogen storage alloy apparatus 60 and the hydrogen storage alloy of the hydrogen storage alloy apparatus 61, hydrogen generated from the hydrogen storage alloy of the hydrogen storage alloy apparatus 61 is transported to the hydrogen storage alloy apparatus 60. At this time, the hydrogen storage alloy of the hydrogen storage alloy apparatus 61 captures heat from the heating medium source 71, and the hydrogen storage alloy of the hydrogen storage alloy apparatus 62 is cooled. As a result, due to the difference between the hydrogen dissociation pressures of the hydrogen storage alloys of the hydrogen storage alloy apparatuses 62 and 63, hydrogen discharged from the hydrogen storage alloy of the hydrogen storage alloy apparatus 63 is transported to the hydrogen storage alloy apparatus 62. At the same time, the hydrogen storage alloy of the hydrogen storage alloy apparatus 63 captures heat from the heating medium source 73. By increasing the size of the difference between the hydrogen dissociation pressures of the hydrogen storage alloys of the hydrogen storage alloy apparatuses 62 and 63, the temperature of the heating medium source 73 can be lowered even further. Furthermore, by operating the pump 74, hydrogen can be forcibly transported from the hydrogen storage alloy apparatus 63 to the hydrogen storage alloy apparatus 62. Therefore, the lowering of the heating medium source 73 to an ultra low temperature can be achieved efficiently.

In the reactivation step shown in Fig. 4B, by heating the hydrogen storage alloy apparatus 60 with the heating medium source 70 at a high temperature, hydrogen is generated from the hydrogen storage alloy of the hydrogen storage alloy apparatus 60, the hydrogen pressure inside the hydrogen storage alloy apparatus 60 is raised, and hydrogen is transported to the hydrogen storage alloy apparatus 61. The hydrogen

storage alloy of the hydrogen storage alloy apparatus 61 that has absorbed hydrogen transported from the hydrogen storage alloy apparatus 60 generates heat and imparts this heat to the hydrogen storage alloy apparatus 62. The hydrogen storage alloy of the hydrogen storage alloy apparatus 62 whose temperature has been raised by the heat  
5 supplied from the hydrogen storage alloy apparatus 61 discharges hydrogen. Hydrogen discharged from the hydrogen storage alloy of the hydrogen storage alloy apparatus 62 is transported to the hydrogen storage alloy apparatus 63 that is connected to the hydrogen storage alloy apparatus 62, and the hydrogen storage alloy of the hydrogen storage alloy apparatus 63 that has absorbed this hydrogen discharges heat. At this time, the pump 74  
10 is not operated and the hydrogen storage alloy apparatus 62 is in a state of connection with the hydrogen storage alloy apparatus 63.

In the reactivation step, the connections between the hydrogen storage alloy apparatus 63 and the heating medium source 73 and between the hydrogen absorbing apparatuses 61 and 62 and the heating medium source 71 are each terminated, and the  
15 heating medium source 71 is connected to the hydrogen storage alloy apparatus 63. By employing this type of structure, waste heat from the hydrogen storage alloy apparatus 63 is received by the heating medium source 71 thereby raising the temperature thereof.

The heating medium source 71 that is now at a high temperature can thus become a source of supply of heat to the hydrogen storage alloy apparatus 61 in the formation step.

20 In addition, as described above, if the quantity of the hydrogen storage alloy of the hydrogen storage alloy apparatus 61 is greater than the quantity of the hydrogen storage alloy of the hydrogen storage alloy apparatus 62 in the formation step, then the heating medium source 71 can be set to an even lower temperature. If this heating medium source 71 is then used in the reactivation step, the receiving of heat from the hydrogen  
25 storage alloy apparatus 63 by the heating medium source 71 can be performed even more

efficiently.

As described above, by using the heat pump 50, it is possible to achieve a compact and efficient heat pump. Furthermore, by using hydrogen transporting by pump together with a heating medium, it is easy to achieve ultra low temperatures that are difficult to obtain using only a heating medium source.

(Third Embodiment: Heat pump)

A heat pump 80 according to the third embodiment will now be described with reference to Fig. 5.

The heat pump 80 forms a two system hydrogen transport path via a single pump unit 90 and achieves extremely low temperatures. The two system hydrogen transporting paths are made up of a first system that joins a hydrogen storage alloy apparatus 100 and a hydrogen absorbing apparatus 101 that are connected via the pump unit 90; and a second system that joins a hydrogen storage alloy apparatus 102 and a hydrogen absorbing apparatus 103 that are connected via the pump unit 90. Fig. 5 shows a simplified view in which the hydrogen storage alloy apparatuses 100, 101, 102, and 103 each form a unit of the hydrogen storage alloy unit 10 shown in Fig. 1. Namely, the hydrogen storage alloy apparatuses 100, 101, 102, and 103 are each formed by the hydrogen storage alloy pipes 41 and 42 of the hydrogen storage alloy unit 10, while the hydrogen storage alloy of the hydrogen storage alloy apparatuses 101 and 102 are also each formed by the hydrogen storage alloy pipes 41 and 42 of the hydrogen storage alloy unit 10. Note that the hydrogen storage alloy apparatuses 100, 101, 102, and 103 may also each be formed with a different structure from that of the hydrogen storage alloy unit 10, however, if they are formed using the structure of the hydrogen storage alloy unit 10 there is only a small heat loss when the heating medium source is exchanged.

Looking at the hydrogen storage alloys of the hydrogen storage alloy

apparatuses 100, 101, 102, and 103, the hydrogen storage alloy apparatus (i.e., the first hydrogen storage alloy apparatus) 100 and the hydrogen storage alloy apparatus (i.e., the fourth hydrogen storage alloy apparatus) 103 have the same type of hydrogen storage alloy, while the hydrogen storage alloy apparatus (i.e., the second hydrogen storage alloy apparatus) 101 and the hydrogen storage alloy apparatus (i.e., the third hydrogen storage alloy apparatus) 102 have the same type of hydrogen storage alloy. The hydrogen dissociation pressure of the hydrogen storage alloy of the hydrogen storage alloy apparatuses 100 and 103 is higher than that of the hydrogen storage alloy apparatuses 101 and 102, and respective hydrogen storage alloys are used that have characteristics that correspond to the target heat collection temperature.

The pump unit 90 has a pump 91, switchover valves 92, 93, 94, and 95, and one-directional valves 96 and 97. The switchover valves 92 and 93 are connected to the hydrogen storage alloy apparatus 100. The one-directional valve 96 is provided down stream from the pump 91 and permits flow from the pump 91 to the hydrogen storage alloy apparatus 101 while blocking flow from the hydrogen storage alloy apparatus 101. The switchover valves 94 and 95 are connected to the hydrogen storage alloy apparatus 103. The one-directional valve 97 is provided down stream from the pump 91 and permits flow from the pump 91 to the hydrogen storage alloy apparatus 102 while blocking flow from the hydrogen storage alloy apparatus 102.

In the formation step of the first system of the heat pump 80 having the above described structure, when the switchover valve 92 is closed and the switchover valve 93 and the one-directional valve 96 are open, the high temperature hydrogen storage alloy apparatus 101 is cooled at room temperature. Consequently, as a result of the difference in the dissociation pressures of the hydrogen storage alloys of the hydrogen storage alloy apparatuses 101 and 100, hydrogen is discharged from the hydrogen storage alloy of the

hydrogen storage alloy apparatus 100 and is transported to the hydrogen storage alloy apparatus 101. If the pump 91 is operated at this time, the transporting of the hydrogen from the hydrogen storage alloy apparatus 100 to the hydrogen storage alloy apparatus 101 is carried out efficiently. Furthermore, by forcibly transporting hydrogen using the pump 91, the hydrogen storage alloy of the hydrogen storage alloy apparatus 100 is able to capture a greater quantity of heat from the heating medium source 105 that is connected to the hydrogen storage alloy apparatus 100. Therefore, this heating medium source can be taken to an extremely low temperature.

At this time, in the second system, when the switchover valve is open and the switchover valve 94 and the one-directional valve 97 is closed, hydrogen is discharged from the hydrogen storage alloy apparatus 102 in an opposite direction to the first system and is transported to the hydrogen storage alloy apparatus 103. The reactivation step is then performed.

As the heating medium sources 106 and 108 that perform cooling at this time, the natural outside temperature including snow and ice may be used. As the heating medium source 107 that performs heating, solar heat, geothermal heat, factory waste heat, heat from garbage burning, combustion heat such as from burning fuel, fuel cell waste heat, and waste heat from operating machinery and the like can be used.

In the heat pump 80, hydrogen is transported in the first system from the hydrogen storage alloy apparatus 100 to the hydrogen storage alloy apparatus 101. In the second system, hydrogen is transported from the hydrogen storage alloy apparatus 102 to the hydrogen storage alloy apparatus 103. By switching over the switchover valves 92 to 95 and the one-directional valves 96 and 97, a reverse process to restore hydrogen that is transported like this to its original hydrogen storage alloy apparatus can be performed.



Namely, as a reverse process, in the first system, when the switchover valve 93 and the one-directional valve 96 are closed and the switchover valve 92 is open, by raising the temperature of the heating medium source 106 connected to the hydrogen storage alloy apparatus 101, the reactivation step is performed by discharging hydrogen from the hydrogen storage alloy of the hydrogen storage alloy apparatus 101, and transporting hydrogen to the hydrogen storage alloy apparatus 100 that has a greater hydrogen dissociation pressure than the hydrogen storage alloy of the hydrogen storage alloy apparatus 101.

On the other hand, in the second system, when the switchover valve 94 and the one-directional valve 97 are open and the switchover valve 95 is closed, the formation step is performed by operating the pump 91 so that hydrogen is transported from the hydrogen storage alloy apparatus 103 to the hydrogen storage alloy apparatus 102.

As the heating medium sources 105 and 107 that perform cooling at this time, the natural outside temperature including snow and ice may be used. As the heating medium source 106 that performs heating, solar heat, geothermal heat, factory waste heat, heat from garbage burning, combustion heat such as from burning fuel, fuel cell waste heat, and waste heat from operating machinery and the like can be used.

By employing the above described structure, an extremely low temperature heating medium source can be created and the step to reactivate the heat pump 80 can be repeated without the heating medium source having to be stopped. Furthermore, because the heat pump 91 can be continuously driven by one of the first system and second system, it is possible to prevent failures that are caused by the pump being driven intermittently.

(Fourth Embodiment: Hydrogen compression apparatus)

A hydrogen compression apparatus 110 according to the fourth embodiment of

the present invention will now be described with reference to Figs. 6A and 6B.

The hydrogen compression apparatus 110 stores compressed hydrogen in a hydrogen storage container 125 and has a low pressure hydrogen storage container 120 that is designed to refine and improve the hydrogen, the hydrogen storage container 125  
5 designed for high pressure storage, a hydrogen storage alloy apparatus 121, a heating medium source for cooling 122, a heating medium resource for heating 124, and a pump 123.

The hydrogen storage alloy apparatus 121 can be given an optional structure, and the hydrogen storage alloy unit 10 shown in Fig. 1 can also be used. In this case, it  
10 is preferable that hydrogen storage alloys having the same hydrogen dissociation pressure are installed in the hydrogen storage alloy pipes 41 and 42. The installation of the hydrogen storage alloy is performed by filling the hydrogen storage alloy pipes 41 and 42 with a hydrogen storage alloy in paste form, and then hardening this paste.

The hydrogen compression apparatus 110 having the above described structure  
15 is able to achieve a cycle that is formed by a hydrogen storage step (Fig. 6A) in which hydrogen is stored in the hydrogen storage alloy apparatus 121, and a hydrogen compression step (Fig. 6B) in which hydrogen is stored under pressure in the hydrogen storage container 125.

In the hydrogen storage step, the hydrogen storage alloy apparatus 121 is cooled  
20 by the heating medium source 122 at room temperature. Consequently, the hydrogen storage alloy inside the hydrogen storage alloy apparatus 121 absorbs hydrogen that is present inside the hydrogen storage apparatus 120:

On the other hand, in the hydrogen compression step, the heating medium source 124 is maintained at a high temperature, and the temperature of the hydrogen  
25 storage alloy apparatus 121 connected to the heating medium source 124 is raised.

Hydrogen is discharged when the temperature of the hydrogen storage alloy apparatus 121 reaches hydrogen discharge start temperature of the hydrogen storage alloy of the hydrogen storage alloy apparatus 121. A valve provided between the hydrogen storage container 125 and the pump 123 is opened and the discharged hydrogen is stored in the hydrogen storage container 125. In this step, the pump 123 whose intake is on the hydrogen storage alloy apparatus 121 side thereof and whose outlet is on the hydrogen storage container 125 side thereof is operated, and hydrogen that has been discharged by the hydrogen storage alloy of the hydrogen storage alloy apparatus 121 is forcibly stored in the hydrogen storage container 125. As a result, it is possible to store hydrogen in a highly pressurized state in the hydrogen storage container 125.

For example, if the heating medium source 124 is heated by a heat exchange with waste heat having a temperature of approximately 60 to 90°C, the hydrogen discharge pressure of the hydrogen storage alloy of the hydrogen storage alloy apparatus 121 is raised to approximately 10 to 20 kg/cm<sup>2</sup>, and pressure is applied to the intake side of the pump 123 (i.e., to the hydrogen storage alloy apparatus 121 side thereof), then it is easy to raise the outlet side pressure of the pump 123 to a high pressure.

(Fifth Embodiment: Hydrogen compression apparatus)

A hydrogen compression apparatus 130 according to the fifth embodiment of the present invention will now be described with reference to Fig. 7. The hydrogen compression apparatus 130 stores compressed hydrogen in a hydrogen storage container 140 and has a hydrogen storage container 140, a hydrogen storage alloy apparatus 141, pressure containers 142 and 143, and a pump 144.

The hydrogen storage alloy apparatus 141 is connected to the pressure containers 142 and 143 via a non-return valve 150 that only permits a flow from the hydrogen storage alloy apparatus 141 to the outside, a non-return valve 152 that branches

off from the non-return valve 150 and only permits a flow from the non-return valve 150 to the pressure container 142, and a non-return valve 153 that branches off from the non-return valve 150 and only permits a flow from the non-return valve 150 to the pressure container 143.

5           The pressure containers 142 and 143 are connected to the hydrogen storage container 140 via non-return valves 154 and 155 that only permit a flow from the pressure containers 142 and 143 to the hydrogen storage container 140. A switchover valve 156 is positioned between the non-reverse valves 154 and 155 and the hydrogen storage container 140. In addition, the pump 144 that is capable of two-directional  
10 transporting is positioned between the pressure containers 142 and 143. As a result of this layout, hydrogen discharged from the hydrogen storage alloy of the hydrogen storage alloy apparatus 141 can be selectively transported to either one of the pressure containers 142 and 143.

          The hydrogen storage alloy apparatus 141 can be given an optional structure,  
15 and the hydrogen storage alloy unit 10 shown in Fig. 1 can be used. In this case, the hydrogen storage alloy pipes 41 and 42 are filled with hydrogen storage alloys having the same hydrogen dissociation pressure. The heating medium source 145 is connected to the nozzles 14 and 15, and the open ends of the hydrogen storage alloy pipes that are filled with hydrogen storage alloy of the hydrogen storage alloy pipes 41 and 42 are  
20 connected to the non-return valve 150 via the hydrogen chambers and the nozzles. As the heating medium source, the natural outside temperature including snow and ice, solar heat, geothermal heat, factory waste heat, heat from garbage burning, combustion heat such as from burning fuel, fuel cell waste heat, and waste heat from operating machinery and the like can be used.

25           The pressure containers 142 and 143 each form a liquid surface piston formed

by a closed container in which a working fluid 160 is contained. Water, for example, may be used as the working fluid. If water is used, it is preferable that the water is pure water or distilled water. Because the pressure containers 142 and 143 are connected via the pump 144, if the non-return valve 152 is opened and the non-return valve 153 is closed, then hydrogen discharged from the hydrogen storage alloy of the hydrogen storage alloy apparatus 141 enters the pressure container 142 and pushes down the working fluid 160 inside the pressure container 142. This working fluid 160 then enters the pressure container 143 and hydrogen present above the working fluid 160 inside the pressure container 143 is stored in the hydrogen storage container 140. Conversely, if the non-return valve 153 is opened and the non-return valve 152 is closed, then hydrogen discharged from the hydrogen storage alloy of the hydrogen storage alloy apparatus 141 enters the pressure container 143 and pushes down the working fluid 160 inside the pressure container 143. This working fluid 160 then enters the pressure container 142 and hydrogen present above the working fluid 160 inside the pressure container 142 is stored in the hydrogen storage container 140.

Next, the steps of the hydrogen compression storage in the present embodiment will be described.

In the first step, hydrogen discharged from the hydrogen storage alloy of the hydrogen storage alloy apparatus 141 is made to flow into the pressure container 142 (i.e., the pressure container on the hydrogen intake side: a first hydrogen container), and hydrogen inside the pressure container 143 (i.e., the pressure container on the pressurized side: a second hydrogen container) is stored in the hydrogen storage container 140. Specifically, with the non-return valves 150, 153, and 154 and the switchover valve 156 opened and with the non-return valves 155 and 152 closed, if the hydrogen storage alloy apparatus 141 is heated by the heating medium source 145 to which it is connected,

hydrogen discharged from the hydrogen storage alloy thereof passes along a path indicated by the circled numbers (1) → (2) → (3) → (4), and is stored in the hydrogen storage container 140. At this time, by driving the pump 144 so as to force feed the working fluid, the liquid surface piston of the pressure container 142 is lifted so as to pressurize the hydrogen therein. As a result, it is possible to store hydrogen in the hydrogen storage container 140 in a highly pressurized state. As the heating medium sources, for the heating medium source 146 that performs cooling, the natural outside temperature including snow and ice may be used. As the heating medium source 145 that performs heating, solar heat, geothermal heat, factory waste heat, heat from garbage burning, combustion heat such as from burning fuel, fuel cell waste heat, and waste heat from operating machinery and the like can be used.

In the second step, hydrogen discharged from the hydrogen storage alloy of the hydrogen storage alloy apparatus 141 is made to flow into the pressure container 143 (i.e., the pressure container on the hydrogen intake side), and hydrogen inside the pressure container 142 (i.e., the pressure container on the pressurized side) is stored in the hydrogen storage container 140. Specifically, with the non-return valves 150, 152, and 155 and the switchover valve 156 opened and with the non-return valves 153 and 154 closed, if the hydrogen storage alloy apparatus 141 is heated by the heating medium source 145 to which it is connected, hydrogen discharged from the hydrogen storage alloy thereof passes along a path indicated by the circled numbers (1) → (5) → (6) → (7) → (8) → (9), and is stored in the hydrogen storage container 140. At this time, by driving the pump 144 so as to force feed the working fluid from the pressure container 142 to the pressure container 143, the liquid surface piston of the pressure container 143 is lifted so as to pressurize the hydrogen therein. As a result, it is possible to store hydrogen in the hydrogen storage container 140 in a highly pressurized state.

By performing the above described first step and second step alternately, it is possible to store highly pressurized hydrogen in the hydrogen storage container 140.

For example, if the hydrogen storage alloy apparatus 141 is heated by a heat exchange with waste heat having a temperature of approximately 60 to 90°C, then by raising the

5 hydrogen discharge pressure of the hydrogen storage alloy of the hydrogen storage alloy apparatus 141 to approximately 10 to 20 kg/cm<sup>2</sup>, and applying pressure, the volume of the interior of that pressure container out of the pressure container 142 and the pressure container 143 that is on the hydrogen intake side can be temporarily shrunk (i.e., primary compression) as the hydrogen is introduced. Therefore, hydrogen can be easily  
10 transported to the hydrogen storage container 140 and compressed (i.e., undergo secondary compression) therein without the pump 144 having to be contracted from normal pressure volume to an ultra high pressure volume. As a result, the time required is also shortened compared with a conventional apparatus.

The present invention has been described with reference being made to the  
15 above embodiments, however, the present invention is not limited to the above described embodiments and various improvements or modifications thereof are possible as improvements to the present invention or insofar as they do not depart from the scope of the present invention.

## 20 Industrial Applicability

According to the present invention, a hydrogen storage alloy unit includes a heat exchange chamber through which a heating medium source circulates, a pair of hydrogen chambers that are formed on both sides of the heat exchange chamber, and hydrogen storage alloy pipe groups one end portion of which opens into the pair of hydrogen  
25 chambers and whose other end portion extends in a free state into the heat exchange

chamber, and that form a pair whose one end portions that are on the side of the pair of hydrogen chambers are each fixed on that side, wherein a hydrogen storage alloy is provided in an interior of each hydrogen storage alloy pipe forming the hydrogen storage alloy pipe groups that form a pair, and the free end portion on the heat exchange chamber side is closed off while hydrogen circulation holes are open in the end portions on the hydrogen chamber sides. As a result, the effects are achieved that the apparatus can be made more compact and there is little heat loss when switching between heating and cooling of the hydrogen storage alloy. In addition, the transfer of heat between the hydrogen storage alloy and the heating medium source can be performed instantly, and the possibility of the container being ruptured due to expansion when the hydrogen storage alloy is hydrogenated is reduced.